COLUMN ANALYSES CONSIDERATIONS

Bridge Design Specifications seismic criteria can result in extremely dense reinforcement in columns. There are a number of analytical solutions a designer should consider before deciding the column size and spacing best suited for the structure. Following are some recommendations which designers should consider. The recommendations generally apply to long or narrow structures.

Span lengths, column sizes, and column architectural features are often selected rather arbitrarily when the General Plan is developed. The first step is to determine whether these arbitrary decisions will actually be practical. Preliminary BDS, bent cap, and dynamic analyses should be made. These analyses may be rather limited at the early design stage. (The dynamic model should encompass the entire structure, including connecting ramps, within program limitations. Long structures can be divided into groups of frames for dynamic analysis, but groups must overlap and suitable springs must be assumed at group ends.) The results should be reviewed for critical column loadings. Those columns suspected to require maximum reinforcement should be analyzed in the YIELD program. If longitudinal and transverse reinforcement is acceptable, the frame arrangements can be assumed satisfactory, and superstructure design may begin. If column reinforcement exceeds preferred maximums, frame revisions are in order. Revisions which may help are:

1) Pin columns in multi-column bents and selected single columns at one end.
2) Add more columns per bent.
3) Use broader single column.
4) Consider continuity at top of single fixed-ended columns which are not true cantilevers.
5) Utilize torsion and distribution to reduce P-load effects on single column bents.
6) Use larger column(s).
7) Use higher strength column concrete.
8) Shorten spans and add bents.
9) Add hinges or consider temporary construction hinge to reduce sensitivity to shortening.
10) Increase elastic length of short columns.
11) Use pile shafts in lieu of footings.
12) Reduce prestress and thermal force coefficients where appropriate.

In addition to the foregoing, the following two items may impact column structural decisions faced by the designer:

1) Aesthetic features.
2) Outrigger bents.

You may wish to use one or a combination of these items. Cost should be the primary consideration, but not the only one. Cost is ambiguous in the sense that it is estimated based on average conditions. Some of the column choices above may not appear cost effective, but may result in savings in other features such as footings. Furthermore, a column congested with reinforcement may be poorly constructed

Supersedes Memo to Designers 6-1 dated October 1985 internally and will not perform as designed at a critical time. Any one of the solutions above may solve one problem, but cause another. Following is a brief review of each solution, citing both beneficial and detrimental effects.

1) *Pin fixed columns:* This method should be the norm for all multi-column bents and a consideration for selected single columns. Seismic effects can be reduced by softening structure response. However, the designer should be aware that the fixed end moment for other loads could increase and result in larger plastic moment and shears. Furthermore, pinned columns act as cantilevers and are thus subjected to higher moment magnification factors in the design stage. The combined effects of increased group load moments at the fixed end and moment magnification could require an increase in primary reinforcement. Short, stiff single columns may be pinned if the abutment or adjacent bent can assume added load and retain stability. Pinned columns must be supported during construction. End columns in frames can also be designed to slide on the footing during prestressing and then externally keyed to footing. The biggest advantage of pinning the column to the footing is reduced foundation size. Pot bearings or base isolation bearings, though expensive, may provide a satisfactory solution in some situations.

2) *Add more columns per bent:* This alternative can usually reduce column size which will reduce the longitudinal stiffness and moments. The frame will be stiffer transversely. Adding columns may not be aesthetically pleasing. Aesthetics is important, but not to the point of sacrificing structural integrity. A second column may be the appropriate solution (for narrow structures, two closely spaced columns may not leave room for flares). Axial tension due to overturning effects may reduce shear capacity in multi-column bents, but other benefits should prevail. Multiple columns will allow pinned connections and significantly cheapen foundations.

3) *Use broader single column:* This choice would be an alternative to adding a second column to a single column bent by providing good lateral stability. The column can be pinned in the longitudinal direction to reduce foundation costs. Use multiple spirals for reinforcement. Ties are not recommended because of the severe requirements for confinement cross ties.

4) *Use available continuity at the top of single fixed-ended columns:* Single columns, fixed at the top, should not be considered as cantilevers (0.99 Distribution Factor) in the transverse direction in the YIELD program. Cantilever moments are magnified significantly in the program. Box girder torsion provides significant restraint. A D.F. of 0.90 can conservatively be used without a frame analysis and will greatly reduce moment and reinforcement. Use STRUDL to obtain actual lower D.F. values if slenderness is significantly increasing the moment magnification factor.

5) *Reduce P-load effects on single-columns through torsion and distribution:* Trial STRUDL analyses shows that superstructure rigidity reduces transverse moments significantly in many single column bent structures as compared to the typical cantilever bent analysis. The standard method of treating a single column bent as a cantilever for maximum transverse moment is quite conservative in box girders. The trial STRUDL analyses shows that a significant portion of wheel loads, applied at a bent near the edge of deck, is distributed to adjacent bents. The designer should

take advantage of a more representative analysis when a preferred single column size/shape is inadequate for the applied Permit Truck load when using the conventional cantilever analysis method. An approximate alternative to a detailed analysis for Permit loads in the maximum transverse load case, is to use only HS live loadings applied in the usual conservative cantilever manner. The trial STRUDL analyses show that distributed Permit loads caused reactions in the column being analyzed, which were similar to reactions caused by HS loads analyzed in the usual cantilever manner. Bridges with unusually large span-to-width ratios (i.e.: connector ramps) are not good candidates for the approximate method.

6) *Use larger column(s):* A larger column section will allow more room to place main reinforcement and provide greater shear capacity. However, if the column is relatively short it could draw more moment and shear and cancel the increased space benefit. Furthermore, foundation cost could increase because of a magnified plastic moment. This option may not be permitted if horizontal roadway clearances are tight or if existing columns are being matched.

7) *Use higher strength column concrete:* This option may be used as a means of reducing main reinforcement without significantly increasing stiffness. Effects on plastic moment may be significant. There will be an increased shear resistance unless tensile axial loads exist. The designer should consider the economics of specifying more than one high strength concrete design in the case of prestressed bridges. The designer should be cautioned not to use a ½" × No. 4 primary aggregate as a method to allow a more closely spaced, dense network of column reinforcement. This type of material is not readily available in all areas and may require concrete additives to reach assumed strength.

8) *Shorten spans and add bents:* This solution is primarily for viaducts. Other long structures (connector ramps) generally have bent locations dictated by lower roadways. Shorter spans can reduce structure depth (i.e., dead load) and proportionately reduce seismic loads to bents. In lieu of reducing structure depth, a structure could be reinforced rather than prestressed. This solution would retain nearly equivalent dead load, but eliminate prestress moments in columns, reduce movement ratings at joints and thus provide less expensive seals. Short prestressed spans reduce dead load, but may be too shallow to develop column bars even when considering bar development length reductions for higher strength concrete.

9) *Add hinges:* This is a solution primarily for long, prestressed structures. Adding a hinge will effectively shorten all frames in a structure. The end bents of the frames, especially short ones near abutments, will draw less prestress moment. The structure will probably become looser for seismic analysis resulting in increased deflections, but also the benefit of reduced force levels due to a lengthened primary response period. Intermediate construction hinges, or selected reinforced concrete segments within long prestressed structures can be strategically used to allow for creep forces to stabilize before connecting frames together.

10) *Increase elastic length of short columns:* Significant moment reductions can be achieved, especially in prestressed structures, by increasing the column elastic length. This can be accom-

plished by taking advantage of footing translation due to elastic and plastic soil deformation, lowering the footing elevation, or both. If the footing is lowered, passive earth resistance will be increased on the footing and on piles which will result in less translation. Soil springs can be used with the STRUBAG program to model foundation releases from full fixity.

11) *Use pile shafts in lieu of footings:* This technique will deliver benefits similar to increasing the column lengths. Generally, seismic forces are reduced, but displacements will increase because of a longer moment arm of the column. Shaft construction is complicated by groundwater and/or loose sand. Elastic column lengths can be increased by specifying the top of shaft below the groundline and requiring a spacer casing around the underground portion of column. Shafts not requiring unusual construction techniques are significantly cheaper than fixed pile footings.

12) *Reduce prestress and thermal force coefficients:* There are a variety of theories concerning effects of prestress and thermal forces on a structure. Some experts feel that initial moments in columns due to prestress shortening eventually creep to nearly zero. Thermal forces in massive concrete structures are not instantaneous. The gradual thermal application allows for some plastic relief. In addition to moment reductions due to creep, the elasto-plastic characteristics of the soil surrounding the foundations also permit some moment relief for the columns. Some reduction in these forces should be utilized. Since there is no agreement on allowable reductions, it is suggested that moments and shears due to prestressing could be reduced 50%, and those due to thermal action be reduced 25%. These values are considered reasonable when applied to fixed foundations. When allowing limited foundation release using springs or some foundation translation, or if shafts are being used, the prestress and thermal forces should not be adjusted as radically. Therefore, adjustments must be used consistent with the analysis model.

Added considerations which impact column type selection, analysis and design:

1) *Aesthetic features:* Aesthetic features often require fascia concrete such as flares, which add stiffness for normal service loads, but can be expected to fail during severe seismic activity. The flares must be attached to the bent cap (horizontal shear criteria) and to the central spiral core (ACI corbel criteria) sufficiently to resist applied service loads. However, they should not be considered effective for seismic forces because it would require a congested network of seismic ties. The designer must be certain that the structure is stable for dead and live load if the flares fail during and earthquake and the structure is supported only by the spiral core. Therefore, the bent cap design must be performed also for both dead and live load assuming the flares are nonexistent. Broad columns or piers must have intersecting spirals or a complex tie arrangement to be entirely effective under seismic conditions. Intersecting spirals must be adequately interlocked by longitudinal reinforcement. If non-overlapping spirals are used, the bent must be seismically modeled as a multiple column unit assuming that concrete between spirals will spall away. It is important that the designer remember that the structure may behave drastically different under seismic loads than it will under other loads, and analyze the structure accordingly. All architectural or filler concrete must be nominally reinforced.

2) *Outrigger bents:* Outriggers are very vulnerable to seismic activity because they do not have superstructure concrete enclosure at the column-cap joint. The joint must be confined with sufficient closed ties with seismic hooks to prevent degradation during plastic hinging. Also, the joint must be designed to guarantee plastic hinging in the column and not in the cap. Therefore, Mp(column) $\leq$ øMn(cap). The exposed portion of the cap must be investigated for torsion and reinforced with closed seismic ties if torsion is significant. The corner joint must be capable of resisting all torsion, moment, and shears applied by both the outrigger and column in addition to supplying confinement for developing bars from both the outrigger and column. Appropriate analysis and calculations must be performed to assure that loads are resisted and confinement is provided in the joint.

In conclusion, it is important to emphasize that the designer be aware of all the preceding factors which are applicable to the structure being analyzed. Attention should be given to producing a dynamic model representing actual site conditions rather than assumed general practice methods when column design problems arise. Secondary effects should be investigated when large column deflections are indicated by analysis. The columns should be investigated early in the design. Leaving column design until last can result in redesign and many wasted hours of work.

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